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REMOTE SENSING - THE APPLICATION OF SPACE TECHNOLOGY TO THE SURVEY OF THE EARTH AND ITS ENVIRONMENT

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INTRODUCTION

Over the past 15 years this nation has taken the lead in space exploration through the successful development and deployment of scientific, exploratory, and applications spacecraft culminating with the spectacular Apollo flights. The investment of our country in these programs has bolstered the economy, increased our scientific and technical competance, improved the quality of life of our nation, and increased our sense of national prestige. We now stand poised to capitalize on the substantially similar benefits promised through the continued growth of our capability in space applications toward improved world-wide communications satellite networks, more accurate long-range weather forecasts, and a better understanding of the Earth, its environment, and its resources.

It has been estimated that by the year 2000, the world will contain almost twice the number of people living today. This large increase in population together with a rising standard of living and a rapidly increasing economy throughout the world will greatly increase the pressure on the world's natural and cultural resources. To meet the increased demands for such resources, we must accelerate the acquisition of knowledge concerning them. Fortunately, science and technology offer potentially powerful new tools for measuring, describing, and understanding the natural and social environment of the world.

In recent years aircraft have provided a new vantage point from which to obtain this information. Today, the use of remote sensing instruments aboard earth-orbiting spacecraft is proving an even more powerful tool for the examination of the Earth and its environment.

When the term "Earth Resources" is used, it refers to much more than valuable minerals; it refers to all the conditions on the Earth's surface which are of economic or social interest to humanity. "Remote Sensing," on the other hand, refers to an ability to obtain information about an object at a distance. Broadly defined, Remote Sensing denotes the joint effects of employing modern sensors, data processing equipment, processing algorithms, modern telemetry capability, and aircraft and spacecraft platforms for the purpose of carrying out surveys of the Earth.

EARTH RESOURCES SURVEY PROGRAM

During the last 8 years, scientists from the National Aeronautics and Space Administration (NASA) together with scientists from various other government agencies as well as from the scientific community have been investigating the feasibility and practicality of using satellites for the remote study of the Earth. The overall objectives of the Earth Resources Survey Program are to determine the information which can best be acquired from space and to develop the capability for the acquisition and utilization of such information.

The current goals of this program are: (1) to evaluate the potential and compare the capability of aircraft and spacecraft for Earth resources information acquisition; and (2) to develop efficient techniques for information acquisition, processing, analysis, storage, and distribution to meet the complex requirements of the many users.

Figure 1, which is a block diagram of an operational Earth Resources System, will help to illustrate the complex relationships involved between the collection of remote sensing data and their successful utilization. Only when such data are incorporated with appropriate Earth science and management decision models and then subsequently used in a decision-making action bearing upon a resource problem can these data be considered beneficial.

These benefits can be considered in terms of dollars (tangible benefits) or in terms of achieving public goals (intangible benefits). The tangible benefits may be equally as important in justifying the cost of remote sensing operations as such tangible benefits as potential cost saving reductions in obtaining imagery and survey information. In examining various remote sensing applications, it is important to consider who will use this information, how it will be used, and what are some of the potential benefits that might be realized.

SENSOR SYSTEMS

A wide variety of sensors both photographic and non-photographic are being used in Earth resources applications. Photography has been and will continue to be one of the most popular means of acquiring remote sensing information. Aerial photography using the visible portion of the electro-magnetic spectrum has been in use since World War 1. Present technology, however, makes it possible to produce images over a wide spectral range including ultraviolet, infrared and microwave wavelengths.

Cameras, although small, light in weight, and relatively simple to operate, have two serious limitations in remote sensing applications. First, the output is a photograph which is difficult to telemeter or to process for computer analyses. Second, photographic film is limited in spectral response to the region from the near ultraviolet (0.36 μm) to the near infrared (0.9 μm).

Non-photographic sensors are capable of operating in portions of the spectrum from ultraviolet, infrared, microwave, and radar wavelenghts. There are a number of advantages in resorting to these non-visual regions of the spectrum. Infrared, microwave, and radar systems are capable of both daytime and nighttime operation. Radar systems are not seriously hindered by clouds or bad weather. The data collected by these systems are usually in the form of electronic current and voltage pulses which are easily transmitted to remote locations. In addition, such electronic signals can be recorded on magnetic tape and can later be processed with high speed computers. These non-photographic sensors are, however, generally more complicated, larger in size, and have lower spatial resolution than comparable photographic sensors.

MULTI-SPECTRAL SCANNER

Obtaining imagery in very narrow regions of the spectrum can be extremely valuable in remote sensing applications. Some features such as diseased vegetation or highly acidic soil from strip mining waste will be highlighted within one wavelength interval but will not be discernible at another. An instrument to obtain this type of narrow spectral band imagery is referred to as a multi-spectral scanner (MSS).

Basically, the MSS, Figure 2, is an optical-mechanical scanner whose instantaneous field of view (IFOV) is scanned across the ground scene perpendicular to the direction of flight by means of a motor-driven scan mirror. The forward motion of the aircraft or spacecraft provides the appropriate motion along the flight line to advance the ground scanning pattern so that an image of the scene is built up element by element, line by line.

At any given instant the rotating mirror directs the energy within the IFOV, through the appropriate optics, where it is dispersed by a prism or grating into various wavelength bands and onto an array of detectors. Each detector generates an electrical signal that varies in intensity according to the amount of electromagnetic radiation received within the spectral region viewed by the detector. The output of the detector can then be recorded on magnetic tape or transmitted directly to the ground.

One of the most important properties of the MSS is that each ground scene within the IFOV is in perfect spatial and temporal registration in all spectral bands. Not only can an image of the ground scene be generated for each spectral band but also spectral traces (intensity versus wavelength) can be generated for each scene element within the IFOV. This latter feature is proving very useful in many areas of application especially where automatic data processing is used.

Aircraft MSS being used in the field of remote sensing today generally have ten or eleven bands within the ultraviolet, visible, near

infrared, and thermal infrared regions of the spectrum. A four band MSS is currently providing imagery from the first Earth Resources Technology Satellite (ERTS-1).

SPECTRAL SIGNATURES

The spectral variation of the reflected or emitted radiation is one of the most important properties used to distinguish various resource phenomenon. Every object will yield a distinctive spectral signature or "color fingerprint" that results from its molecular structure and composition. In addition to allowing objects to be distinguished from one another, spectral signatures provide information about the physical, chemical, and biological properties. Diseased vegetation, for example, will have a different spectral signature than healthy vegetation.

Since it is the leaves of a plant rather than its stems, roots, flowers, or fruit which are exposed to the aerial view, the spectral characteristics of a green leaf will be examined. Various aspects of the spectral signature of a typical broadleaved plant leaf are illustrated in Figure 3.

The spectral region between 0.4 μm and 2.6 μm is of primary interest because the incident solar radiation occurs primarily at these wavelengths. The reflectance peak at 0.56 μm accounts for the green coloration of leaves as perceived by the human eye. The decrease in reflectance at wavelengths above and below this green peak is due to the absorption of the incident radiation by the chlorophyll pigmentation within the leaves. The valleys in the reflectance curve at the near infrared wavelengths are due to absorption by liquid water within the leaf.

The high infrared reflectivity of leaves appears to be caused by their internal cellular structure. The cuticular wax on the epidermis or outer surface of the leaf is nearly transparent to visible and near infrared radiation. Very little solar radiation incident to the leaf is reflected by its outer surface. The incident radiation is diffused and scattered through the epidermis to the chloroplast, mesophyll cells, and air cavities within the leaf. The radiation is further scattered within the soft spongy mesophyll tissue and the air trapped between and within the mesophyll tissue. As mentioned, the incident radiation is absorbed in the visible region by the chlorophyll pigmentation within the chloroplast and in the infrared region by the water within the tissues of the leaf. The transmittance spectrum exhibits the same general characteristics as the reflectance spectrum.

The use of aerial infrared photography in the identification and delineation of diseased trees in a citrus orchard is illustrated in Figure 4. A blackfly infestation has promoted the growth of sooty mold deposit. From the spectral signature curve for the reflected radiation,

a loss of intensity is noted in the near infrared region of the spectrum. On an aerial photograph sensitive to the near infrared region, the infected trees appear dark while the healthy trees appear lighter.

Vegetation spectral signatures are generally influenced by leaf physiology, morphology, pigmentation, moisture content, surface coating (mildew, etc.), sun angle, and illumination. The spatial resolution of aerial and satellite imagery will consist of an integrated exposure of ground vegetation, including leaves, shadows, and bare soil. The various orientations and overlapping of leaves within the plant canopy will also influence the spectral signature.

AREAS OF APPLICATION

Identification and location of resources on the Earth is the first step in their development; inventorying them is the first step in their management.

Five broad areas, related to Earth resources are of particular interest for the application of space technology: Agriculture and Forestry Resources, Geography, Cartography, and Cultural Resources, Geology and Mineral Resources, Hydrology and Water Resources, Oceanography and Marine Resources. As previously mentioned, within each of these areas, NASA is working closely with scientists from the Departments of Interior, Agriculture, NOAA, EPA, the Corps of Engineers, various universities, as well as from the scientific community.

In defining and developing remote sensing applications in each of these areas, a coordinated spacecraft, aircraft, and ground observation program is being pursued. This multistage approach includes theoretical analysis, laboratory experimentation, field measurements of selected ground targets, measurements from aircraft at increasing altitudes, and finally measurements from spacecraft altitude. All of these concurrent approaches are essential to ensure balanced and sound research and development and to determine the appropriate roles of spacecraft, aircraft, and ground observations in future operational systems.

AGRICULTURE AND FORESTRY

World population has increased to a level where a critical need exists for increased agriculture and forestry productivity. For resources of this type, which are more or less fixed in quantity, increased productivity must come from more efficient use. To ensure effective management, accurate and timely information on crop and timberland yields, assessment of crop and timberland health, identification of the causes of stress and deterioration are among some of the information needed. Satellites provide a rapid means of obtaining such information on a regional and global scale on a repetitive basis.

For example, remote sensing instruments aboard aircraft and spacecraft can survey the vegetation communities in a given region discriminating between various agriculture crop types; detect the onset of and monitor the spread of disease or insect infestation in crops and timber; delineate soil types and indicate the relative moisture content, salinity, and acidity of various soils.

GEOGRAPHY, CARTOGRAPHY, AND CULTURAL RESOURCES

Remote sensing information in many fields is used to map the status of lands, peoples, and environments and to delineate the changes and rates of change of significant features. Good maps are essential for urban and land use planning, mineral exploration, and highway and utility pipeline planning. In the area of cartography, 100 000 new maps are produced every year in an attempt to keep track of the Earth's changing face. The current map production cycle is at least three years, three years between the acquisition of photography and the distribution of a finished map. This implies that our maps are at least three years out of date when we receive them.

Methods of mapping land use from space photography are simple and straightforward. Repetitive photography from spacecraft has shown urban changes, coastal changes, and the shifting and movement of river channels. This latter information could contribute to future flood control and assist water transportation.

GEOLOGY AND MINERAL RESOURCES

In the past three decades, the United States alone has used more minerals and fuels than did the whole world in all previous history. Within the next twenty years our requirements are expected to double. In the area of geology, space photography is expected to improve the efficiency of prospecting for minerals and fuels as well as improve the observation of large geologic features and relationships, refine structural and stratigraphic interpretations, and monitor changing geologic features.

Infrared and radar systems are particularly effective for some types of prospecting. Infrared photographs can indicate and highlight the presence of salt domes which are frequent surface indicators of underlying oil deposits. Radar, in differentiating between igneous and sedimentary rocks and disclosing previously hidden faults, can provide valuable clues to mineral deposits.

HYDROLOGY AND WATER RESOURCES

An adequate supply of fresh water is absolutely essential to our economy and its continued growth. There is no shortage of fresh water

on Earth. The basic problem is one of poor distribution in space and time. The principal tasks of the hydrologist will be to find water of the highest quality at the lowest cost; to forecast future supply; and to control the location, quantity, quality, and timing of this supply.

Satellite imagery can provide information on the extent of water pollution from industrial and urban wastes, underground discharges of fresh water along coastal shorelines, thermal discharges into lakes and waterways, drainage patterns, amount of soil moisture, mapping of coastal wetlands, and many others.

OCEANOGRAPHY AND MARINE RESOURCES

The development of remote sensing technology has a logical extension to studies and investigations of the world's oceans. The hydrosphere covers approximately seventy percent of the earth's total surface and is one of man's most important resources. Within and under the oceans lie tons of valuable minerals and vast reserves of oil. The oceans supply a good portion of man's food. The bulk of trans-oceanic cargo movement is by ship.

Satellite imagery shows coastal features, beach erosion, gradients between warm and cold ocean masses, river runoff and sedimentation, ice cover, unmapped shoals, and the topography of continental shelves. Areas of up-welling have been discovered from the analysis of some satellite photographs which indicate areas where phytoplankton are carried to the surface, and where fish will be found. Remote data collection buoys can also collect a variety of hydrological and meteorological information which can be relayed by satellite to shore stations.

EARTH RESOURCES TECHNOLOGY SATELLITE

The Earth Resources Technology Satellite (ERTS) program is the nation's first space program to be devoted exclusively to the study of the Earth and its environment. The first Satellite in this program (ERTS-1), Figure 5, was launched in July of 1972. ERTS-1 is circling the Earth every 103.3 minutes (14 times per day) at an altitude of 570 miles. Imagery obtained on each pass covers a ground area 115 miles wide with a slight overlap between preceding and succeeding passes. ERTS-1 covers the entire globe once every 18 days.

Significant findings and studies have already resulted from ERTS imagery primarily in the areas of environmental concern, geology, and agriculture. Some of the many findings include; several lineaments not shown on the geological map of California have been identified (dashed lines, Figure 6) in the Monterey Bay area; discovery of the pooling of sewage and industrial acid waste being dumped just outside the entrance to New York harbor; delineation of lineaments and geomorphologic features in West Texas that roughly outline the major

petroleum bearing uplift and basin structure; discovery by Iran of two previously unknown lakes in that country; incorrect mapping of places in the remote jungles of Brazil by as much as 20 miles; 95% accuracy in identifying five major agriculture crop types within the California's Central Valley; delineation of strip-mining lands. Figure 7 shows a comparison of images from two MSS channels for delineating strip-mined lands. The dark strip-mined areas can easily be seen in the right center of the channel 7 image. In channel 5 the strip-mined area is lighter than the surrounding vegetation as indicated by a comparison of the spectral signatures between bare soil and healthy vegetation. Preliminary results indicate that such imagery will provide the capability for monitoring strip mining and land rehabilitation.

CONCLUSION

Research in the Earth sciences and management of both natural and man-made resources has been hindered by the difficulty of obtaining accurate and timely information on a regional and global scale. Space surveys with remote sensing instruments are simply another means of attempting to attain the total knowledge of our resources needed for sound planning, development, and conservation. The use of Earth orbiting satellites will greatly expand our ability to collect this information. The collection and use of these data and imagery, however, is not an end in itself, but only the means to an end, that of achieving total resource knowledge. Satellite systems will provide a valuable supplement to existing aerial and ground based observation techniques. These initial systems will probably not meet all the requirements, as is usually the case with first attempts. Future developments in gathering Earth resources information may yield benefits currently undreamed of, and these benefits could justify each subsequent step.

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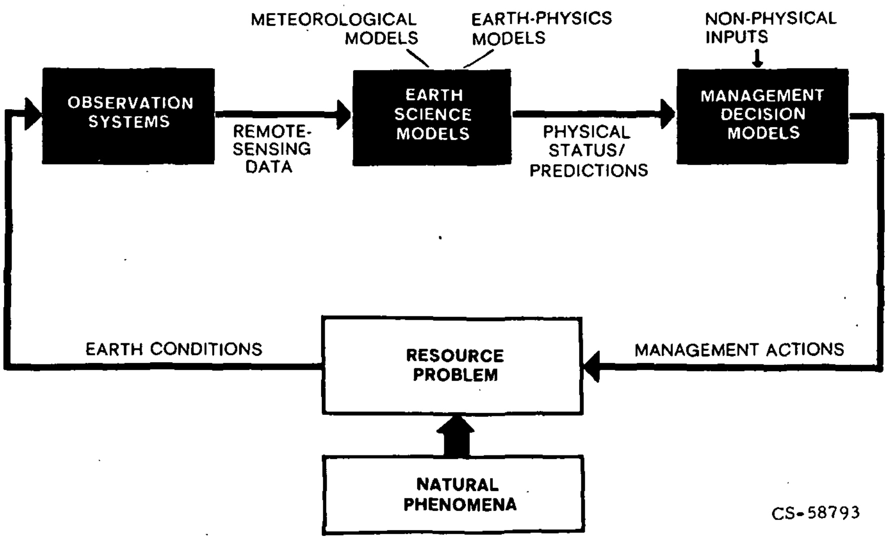


Figure 1. - Block diagram of operational earth resources survey system.

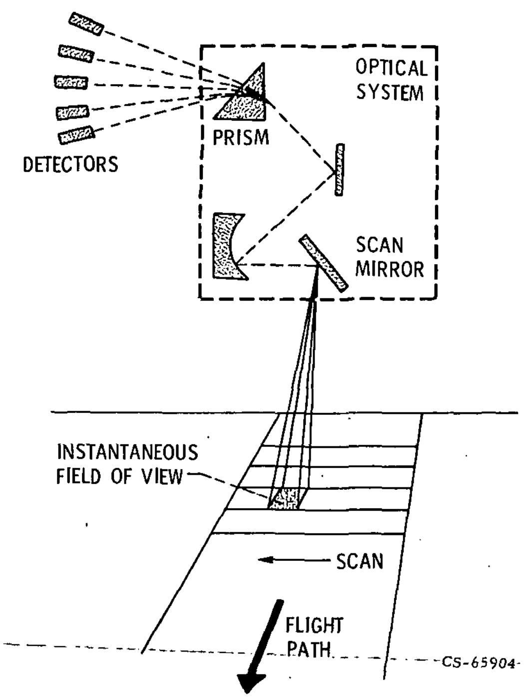


Figure 2. - Schematic diagram of a multi-spectral scanner.

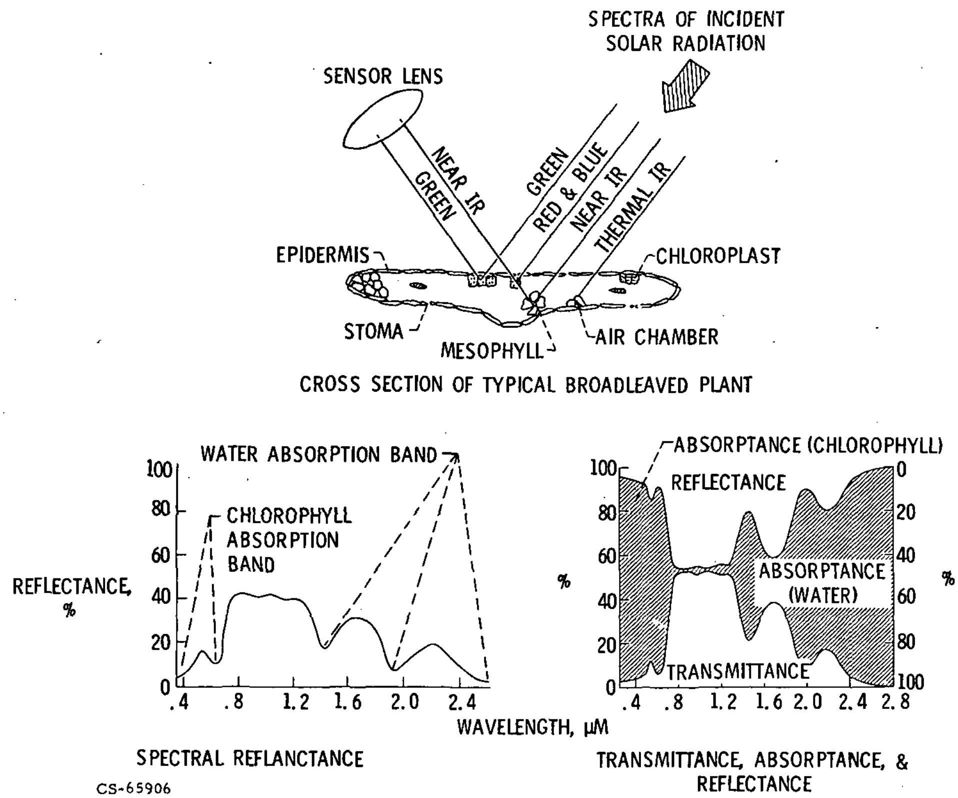
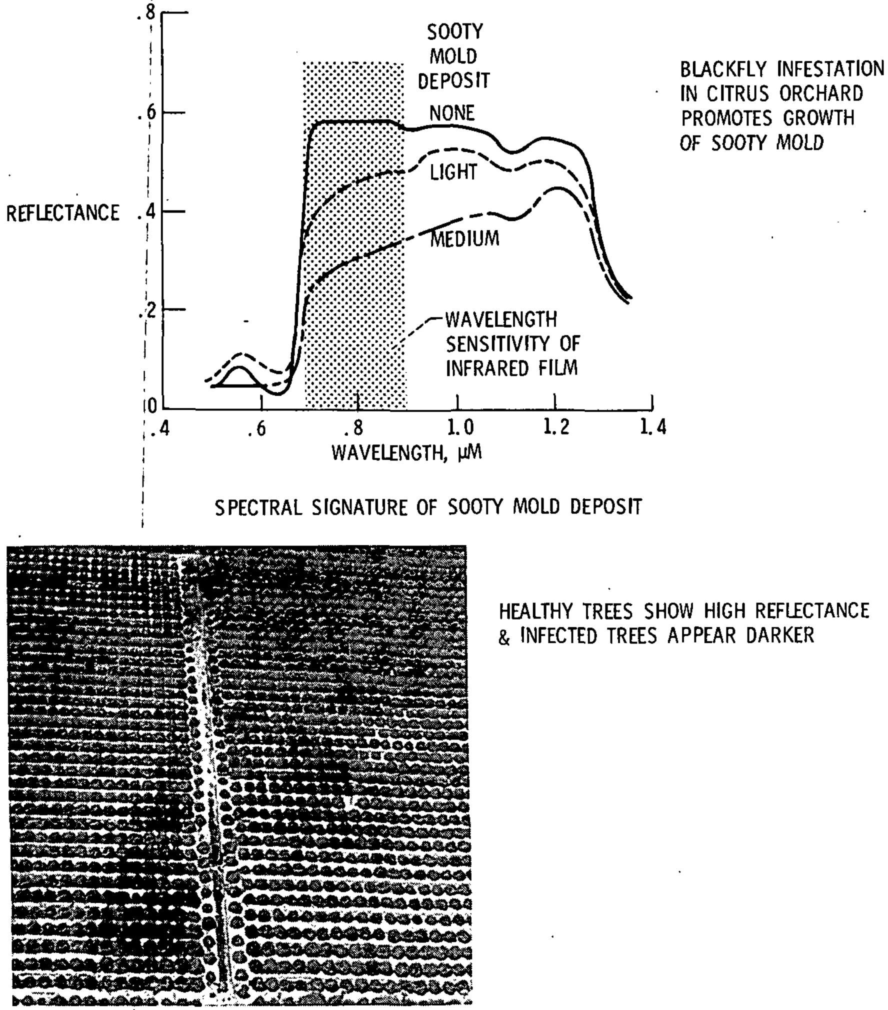


Figure 3. - Composite of various aspects of the spectral signature of a green leaf.



SPECTRAL SIGNATURE OF SOOTY MOLD DEPOSIT

INFRARED PHOTOGRAPH OF CITRUS ORCHARD

Figure 4. - Disease detection using infrared imagery.

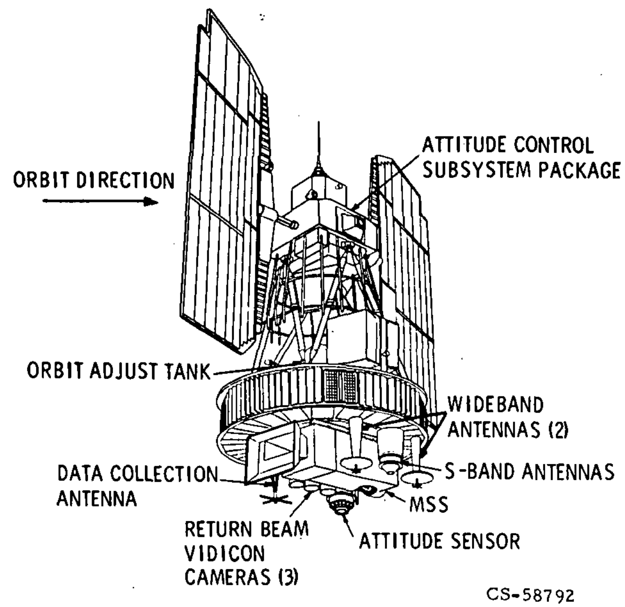


Figure 5. - Earth Resources Technology Satellite, ERTS-1.

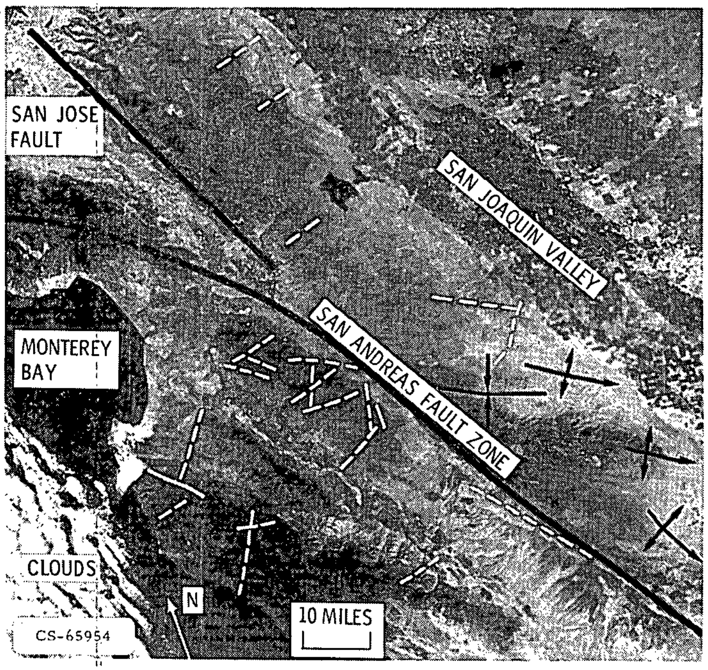


Figure 6. - New geological features detected from ERTS-1 photograph.

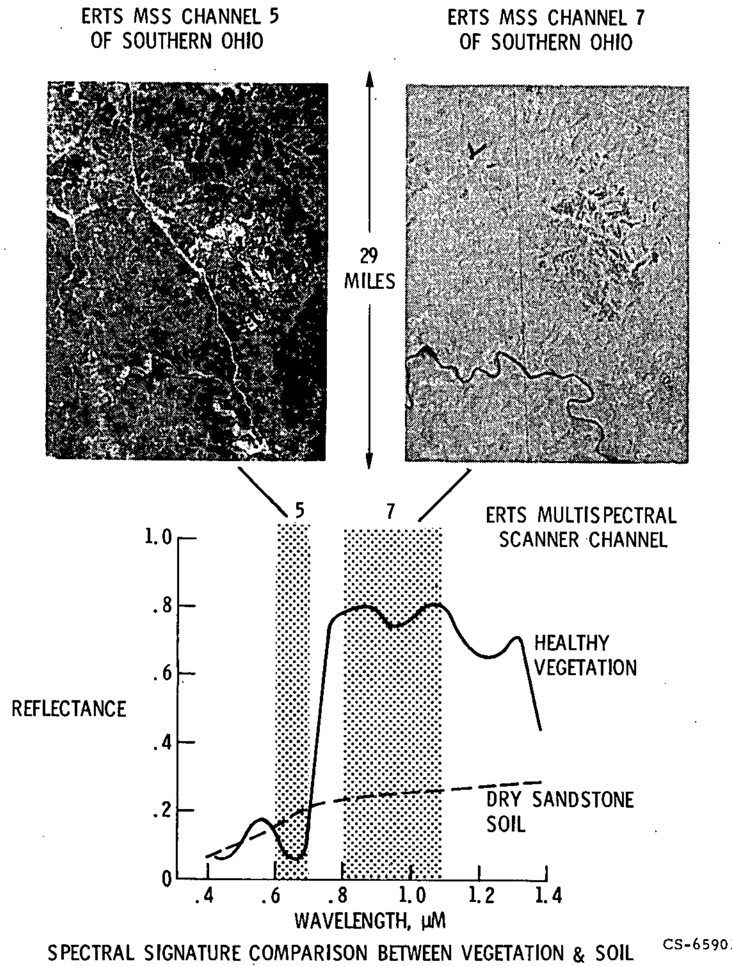


Figure 7. - ERTS imagery provides capability for monitoring strip mining and land rehabilitation.

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